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STREAM RADIOACTIVITY SURVEYS - BIOLOGICAL ASPECTS

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Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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Introduction

It has been pointed out by previous speakers on this forum that many different kinds of samples may be collected and used for radioactivity determinations in a stream radioactivity survey. Among these are water, mud, plankton, filamentous algae, bottom animals, and fish. Studies (1) (2) (3) (4) (5) (6) have shown that certain radioisotopes may be concentrated to a high degree in some aquatic organisms. This fact may be of extreme importance in certain types of surveys, particularly where information is desired as to the effect of radioactivity on aquatic animals such as fish or shellfish or on the use of these animals for human food.

Generally, the type of survey to be made and the water uses or purposes will determine the kinds of samples to be collected. Thus, a study of a water supply used primarily as a source of drinking water may only involve monitoring the raw and finished water. A survey of a stream used for multiple purposes such as industrial, irrigation, or recreational waters, may involve extensive collection and analysis of biological samples.

The collection of certain types of biological samples may influence the location of sampling stations. While the use of waters and the source and nature of radioactive materials primarily determine the location of stations, various types of aquatic organisms have preferred habitats and are much more readily collected in specific areas.

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Concentration of Radioactive Materials in Aquatic Organisms

Many radioisotopes released into receiving waters may be concentrated to a high degree in aquatic organisms. For example, Foster (7) reports that radiophosphorus may be concentrated in various river organisms to levels over 100,000 times that of the water in which they live. Likewise, Krumholz (4) reports a concentration of radiostrontium in fish bone of over 20,000 times.

Radioisotopes are selectively absorbed or concentrated by various aquatic organisms, the degree dependent upon the use of a particular element in the metabolism of the organisms. Radioactive isotopes of an element are used by an organism in the same manner as the non-radioactive element. Thus, radioisotopes of such elements as phosphorus, potassium, calcium, magnesium, manganese, iron, copper, zinc, boron, sulfur, and others which are considered necessary for plant and animal metabolism may be assimilated and concentrated by aquatic organisms. Other isotopes showing some degree of chemical similarity to the above may also be readily utilized. For example, strontium may be utilized as readily as calcium in the bones of aquatic animals.

The uptake of a radioisotope may be dependent upon the amount of the non-radioactive element in the water. If a necessary element is present in limited supply, the concentration of a radioisotope may be much greater than in situations where the same element is abundant. Thus, in the Columbia River, the great affinity of aquatic organisms for radiophosphorus was partially due to the limited supply of phosphate naturally present in Columbia River water.

The degree of absorption of a radioisotope by an aquatic organism may also be dependent upon its position in the aquatic food chain as well as upon the nature of the isotope. Vegetative materials may absorb an element directly from water while aquatic animals may absorb some elements directly through the gills or skin and others only through internal consumption (feeding).

The normal aquatic food chain may be illustrated as follows:

```
                Absorbed
                directly
                                Phytoplankton
Nutrients       ---->           Filamentous algae ----> Zooplankton ---->
                                Higher plants           Bottom animals
                from
                water

                (Small)                                 (Piscivorous)
----> Juvenile  (  or  )  fish  ---->  Adult  (    or     )  fish
                (forage)                                (  game  )

                (Omnivorous)
----> Adult     (    or    )  fish
                (  food  )
```

The terms as used in the chain may be defined as follows:

Plankton - Free-floating microscopic plant and animal life which remains suspended in water and is subject to river currents.

Phytoplankton - Microscopic plant life consisting mostly of diatoms and unicellular green and blue-green algal forms.

Zooplankton - Microscopic animal forms, mostly copepods, cladocerans, rotifers, and protozoans.

Filamentous algae - Sedentary or attached masses of green and blue-green algae usually growing on the bottom or attached to logs, rocks, and other objects in the stream.

Higher plants - Other aquatic vegetation, either suspended or rooted vascular plants.

Bottom animals - Bottom dwelling animals, macroscopic in size, that live in the stream bottom, either on or under rocks or in sand, mud, or aquatic vegetation. Prevalent types are the larvae of such aquatic insects as mayflies, midgeflies, caddisflies, damselflies, dragonflies, and beetles and other invertebrates such as snails, crayfish, and various aquatic worms.

Juvenile (small or forage) fish - Individuals weighing 10 grams or less, and including adults of small species and young of others which may be used as food by game or piscivorous fish.

Adult (game or piscivorous) fish - Larger fish whose diet consists principally of other fish. Includes such species as perch, pike, bass, salmon, and trout.

Adult (food or omnivorous) fish - Large fish such as some species of salmon, whitefish, suckers, carp, catfish, and many others which may be used for human food but would occupy a somewhat different position in the food chain due to their feeding habits.

The accumulation of radioactivity by aquatic organisms appears to follow a definite pattern. The vegetative organisms, phytoplankton, filamentous algae, and higher plants which absorb nutrients (radioisotopes or non-radioactive elements) directly from water, concentrate the most radioactivity. Next are the zooplankton and bottom animals which feed on the plant material and then juvenile fish which feed principally on these animals. At the end of the chain are the adult game fish which feed on the juveniles. There are, of course, some deviations from this pattern.

Some fish may feed directly on plankton, algae, or bottom animals and would reflect higher values, while some bottom animals such as crayfish or snails feeding on dead fish would reflect lower values. The amount of radioactivity in any aquatic animal may depend on the decay rate of the absorbed isotopes (half-life) as well as its food habits.

The concentration of radioactivity in aquatic organisms may be illustrated by previous field studies such as that on the Columbia River by the USPHS (1, 2) and that on White Oak Lake by the TVA (4).

The Columbia River Studies

Columbia River water is used to cool the Hanford reactors. Certain elements present in the cooling water as dissolved or suspended solids are made radioactive when subjected to neutron bombardment within the reactor. Most of the radioisotopes formed are short, half-lived beta emitters, including Cu^{64}, Mn^{56}, Na^{24}, As^{76}, Si^{31}, and P^{32}. Some of these isotopes are concentrated in Columbia River organisms.

This project consisted of a two-year study of the overall effects of Hanford effluents on various river characteristics. Due to the nature of the wastes, the radiological determinations were limited to the determination of gross beta activity density of water, bottom muds, and various kinds of aquatic organisms and the identification of the various radioisotopes by radio-chemical analysis.

The location of sampling stations, Figure 1, reflects sources of effluents, entrance of tributaries and points of water use as well as river areas in which all types of samples could be readily collected. The sampling stations were designated by numbers which indicate river miles

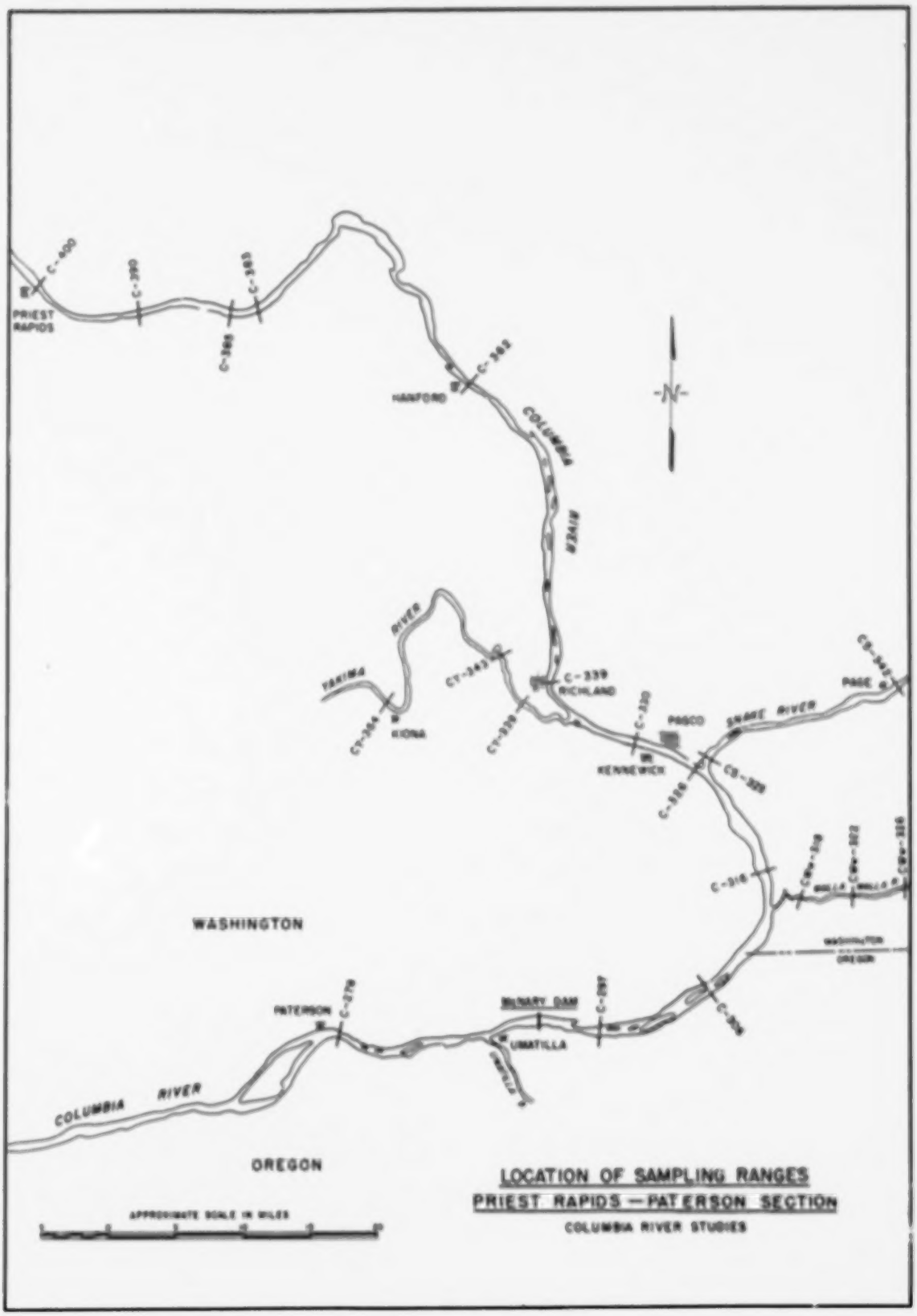

PRIEST RAPIDS
C-300
C-320
C-333
C-352
HANFORD
COLUMBIA RIVER
YAKIMA RIVER
C-343
C-339
RICHLAND
C-330
PASCO
SNAKE RIVER
KENNEWICK
C-328
C-329
C-316
WASHINGTON
OREGON
PATERSON
C-278
MCNARY DAM
C-287
UMATILLA
COLUMBIA RIVER
APPROXIMATE SCALE IN MILES
LOCATION OF SAMPLING RANGES
PRIEST RAPIDS — PATERSON SECTION
COLUMBIA RIVER STUDIES

FIGURE 1

upstream from the mouth of the Columbia River.

The values in Table 1 represent the highest radioactivity levels found in the Columbia River. They illustrate the high concentration of radioactive materials from water and the gradual decrease through the aquatic food chain.

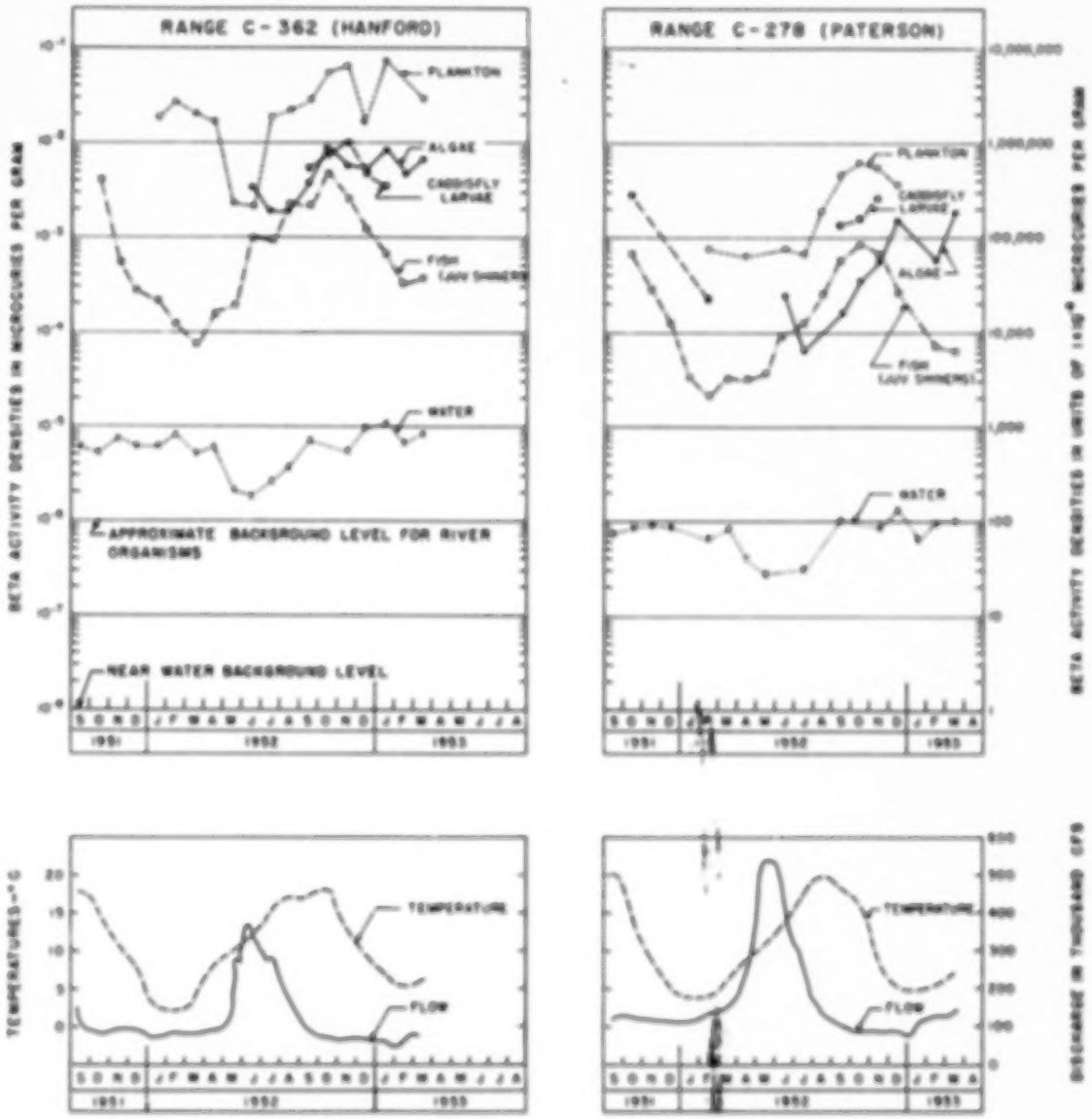
The seasonal variations in activity densities of water, various organisms and fish, as well as the changes in river flows and water temperatures for Ranges C-362 and C-278, are presented in Figure 2. It is evident from these data that activity levels in plankton and algae are directly dependent on the activity in the water, which is in turn dependent upon fluctuations in cooling water discharges and dilution during seasonal river flows.

Activity levels in most aquatic animals, however, are dependent upon their metabolic rates as well as the radioactivity values of the materials upon which they feed. Values for bottom animals were highest at low water stages and high water temperatures. There was a decrease in activity levels with lower water temperature, even though river stages remained low and the material upon which the animals feed remained high in radioactivity.

This decrease was most marked in fish. Some species, such as bass, which stop feeding at low water temperatures, showed very low activity levels during the winter months in spite of the activity levels in the water remaining high. The activity levels in these fish rose rapidly with the resumption of conditions conducive to feeding (higher temperatures), even though water activity levels decreased because of increased river flows. This is not as pronounced in other species such as suckers and

Table 1 - Gross beta activity densities at Range C-362

Type of Sample		Beta Activity Density Units of 10^{-6} Microcuries per Gram	
		Maximum	Average
Water		19	6
Plankton		80,000	20,000
Filamentous Algae		13,000	6,000
Bottom Animals (Caddisfly larvae)		10,000	7,000
Juvenile (forage) fish (shiners)		9,000	1,300
Adult (food) fish (suckers)	Bone	5,000	1,200
	Muscle	1,100	300
Adult (game) fish (bass)	Bone	3,500	200
	Muscle	450	55


RANGE C-362 (HANFORD)
RANGE C-278 (PATERSON)
PLANKTON
ALGAE
CADDISFLY LARVAE
FISH (JUV SHINERS)
WATER
APPROXIMATE BACKGROUND LEVEL FOR RIVER ORGANISMS
NEAR WATER BACKGROUND LEVEL
BETA ACTIVITY DENSITIES IN MICROCURIES PER GRAM
BETA ACTIVITY DENSITIES IN UNITS OF 10⁻⁹ MICROCURIES PER GRAM
TEMPERATURES-°C
TEMPERATURE
FLOW
DISCHARGE IN THOUSAND CFS
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A
1951
1952
1953

SEASONAL VARIATIONS

BETA ACTIVITY DENSITIES

COLUMBIA RIVER STUDIES
1951 — 1953

PLANKTON, ALGAE, CADDISFLY LARVAE, FISH, AND WATER

FIGURE 2

whitefish, which feed to some extent even at low temperatures. Adult salmon which do not feed while in these waters, contained relatively little radioactivity. It is believed that most aquatic animals concentrate radioisotopes of the type encountered in the Columbia River through feeding rather than by other processes such as absorption through the skin or gills.

The highest gross beta activity density values for water and aquatic organisms were found at Range C-362. Primarily by decay and dilution, these values decreased downstream, with a fairly rapid decrease at Range C-339 and a progressive decrease at other downstream ranges (Figure 3). Values at Range C-278 were normally about one-tenth of those at Range C-362. A reasonable amount of radioactivity, somewhat higher than background, remained at the mouth of the river near Astoria, Oregon. Average background values in the Columbia River were at or below 1×10^{-6} μc/gm for aquatic organisms and 1×10^{-8} μc/ml for water.

Radioactive materials were concentrated in all parts of the body of fish. The activity levels were about ten times higher in scales and bone than in skin and flesh, with intermediate values for internal organs, such as the liver, kidney, and sex organs. The relationship between activity levels in bass bone and muscle to other organisms in their food chain at Range C-362 is shown in Figure 4.

Radiochemical analysis and decay studies showed that P^{32} (half-life 14.3 days) is by far the most important radioisotope assimilated by aquatic organisms. While this isotope was responsible for only 1 or 2 percent of the radioactivity in water, it was selectively concentrated

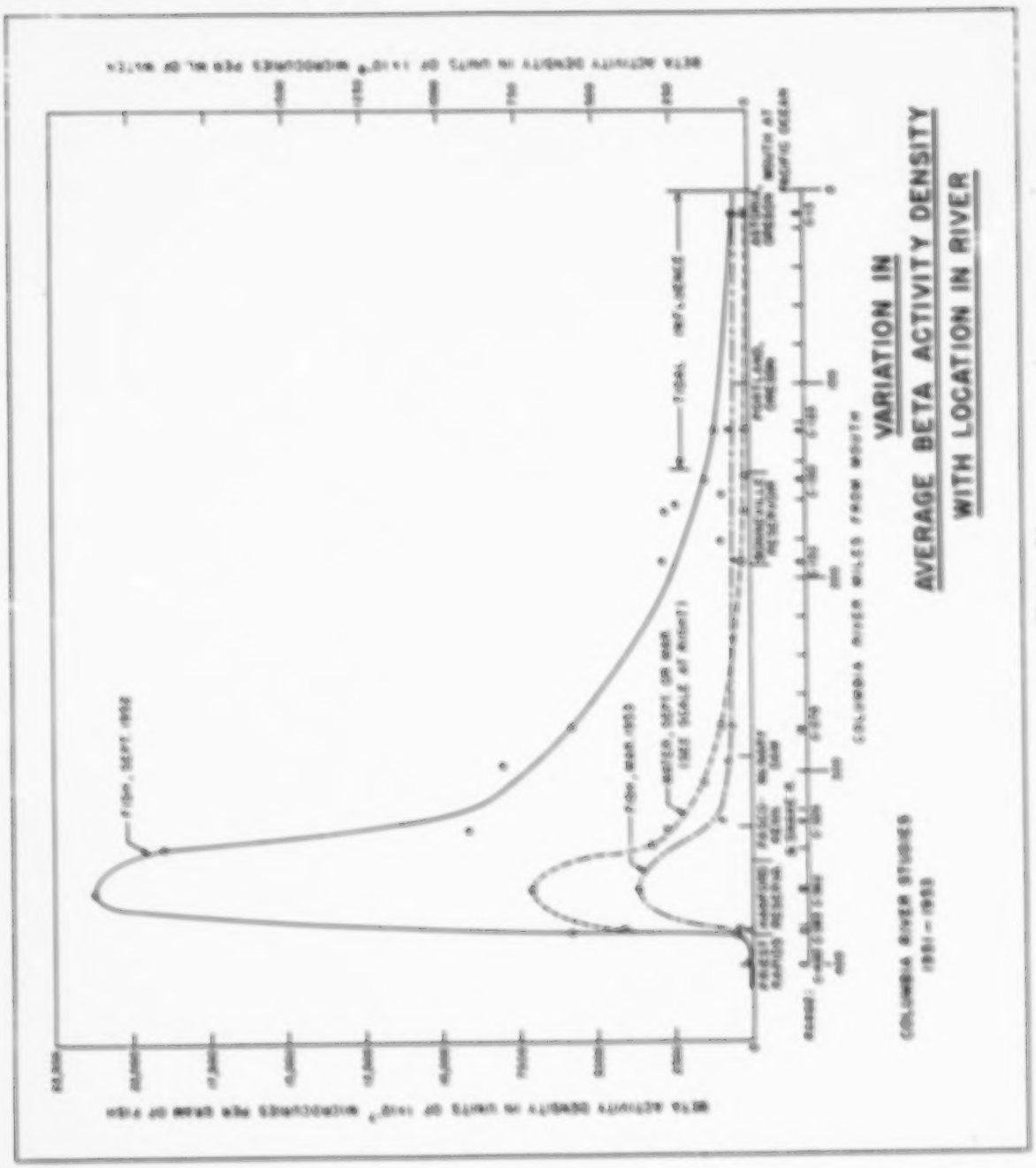


Figure 21

FIGURE 3

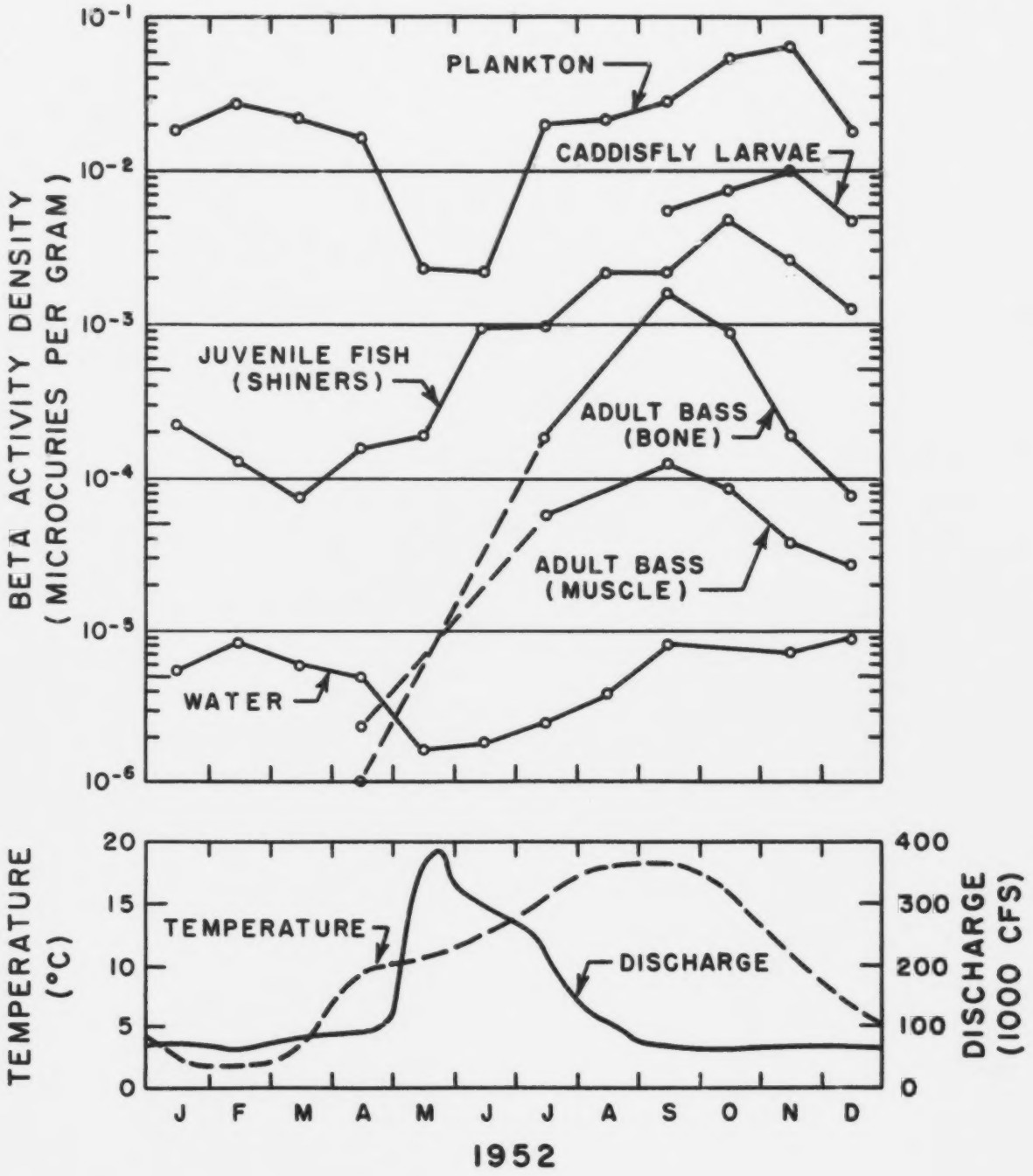

BETA ACTIVITY DENSITY
(MICROCURIES PER GRAM)
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
PLANKTON
CADDISFLY LARVAE
JUVENILE FISH
(SHINERS)
ADULT BASS
(BONE)
ADULT BASS
(MUSCLE)
WATER
TEMPERATURE
(°C)
20
15
10
5
0
TEMPERATURE
DISCHARGE
400
300
200
100
0
DISCHARGE
(1000 CFS)
J F M A M J J A S O N D
1952

FIGURE 4

by aquatic animals and was responsible for over 90 percent of the activity in river fish. Some shorter half-lived isotopes, such as Cu^{64} and Na^{24} were the principal ones absorbed or adsorbed by plankton.

No apparent effects on aquatic populations were observed during this study. Radioactivity levels found in aquatic animals used for human food were not deemed hazardous at present levels. This was primarily due to the concentration of only short half-lived materials. There was no accumulation or build-up from year to year. In other situations, the concentration of longer half-lived material, such as Sr^{90} to beta activity levels found in the Columbia River may present a different picture.

White Oak Lake Studies

This project consisted of a three-year study of the effects of chemical and radioactive wastes from the Oak Ridge National Laboratory on aquatic populations of a 35 acre lake. The radiological studies were quite similar to those in the Columbia River and included the determination of gross beta radioactivity of water and aquatic organism samples and radiochemical analysis to determine the predominant isotopes in the various samples.

The concentration of radioactive materials in aquatic organisms followed a somewhat different pattern from that in the Columbia River. While all organisms appeared to concentrate radioactive materials readily from water, gross beta levels did not as closely follow the food chain, mainly because of selective concentration of different isotopes by different organisms. Gross beta activity levels were high in filamentous algae samples, reaching a maximum of 17,000 counts per minute per gram

(approximately 77,000 x 10^{-6} microcuries per gram, assuming ten percent geometry), and considerably less in bottom animals (midgefly larvae) which contained 2770 c/m/gm (12,500 x 10^{-6} µc/gm) and zooplankton. The highest values, however, were found in fish bone and ranged upward to 19,000 c/m/gm (85,000 x 10^{-6} µc/gm). Values for fish muscle were much lower, ranging upward to 450 c/m/gm (2100 x 10^{-6} µc/gm).

The zooplankton and midgefly larvae had concentrated more radiophosphorus (over 50 percent) than any other radioelement, while in filamentous algae the rare earths were concentrated in amounts (30 percent) almost equal to radiophosphorus. In addition there was an accumulation of definite but small amounts of radiostrontium in all aquatic organisms. In fish bone approximately 85 percent of the radioactivity was emitted by radiostrontium and only 10 percent by radiophosphorus, while in muscle over 75 percent of the activity was from radiocesium, and 10 percent from ruthenium. Other radioelements were concentrated to a lesser degree by the different organisms.

The average amount of radioactivity in the water of White Oak Lake was 4.5 c/m/ml during July 1952, and about 24 percent of the radioactivity was emitted by radiostrontium. The maximum amount of radioactivity detected in the bones of black crapoie caught during the same month was approximately 19,000 c/m/gm. From these data it is apparent that for radiostrontium there is a concentration factor of 20,000 from the lake water to the bones of black crappie. Similar data for bluegills indicate a concentration factor of 30,000.

In the accumulation of radiomaterials there were definite seasonal changes which corresponded somewhat to the seasonal changes in water temperature. However, the accumulation of radiomaterials stopped when the temperature of the water reached its maximum about August 1. The rapid loss of radiomaterials during August and September probably indicates that the fish entered a period of summer dormancy during that time. A residual level of radiostrontium, about one-third of the peak summer concentration, remained in the bone during the winter months and evidently would add to the burden picked up from year to year.

The total body burden of radioactivity carried by a 7-inch crappie during the summer of 1952 was more than a microcurie. The total radiation dose received by the fish in White Oak Lake was estimated to be at least 57 rep per year from external radiation and was probably several times that amount from internal radiation. It was believed that the fish population of White Oak Lake may have suffered deleterious effects as a result of this irradiation.

While no conclusions were drawn regarding the use of these fish for human food, it is believed that they may constitute some hazard, primarily through leaching of radiostrontium from bones while cooking.

Other studies, such as the one on the Mohawk river (5) in connection with wastes from the Knolls Atomic Power Laboratory, have shown a concentration of various radioisotopes such as strontium and phosphorus by aquatic organisms. The uranium mill study (6) reported by Tsivoglou indicates some concentration of radium in aquatic organisms.

The Use of Biological Samples in Stream Surveys

While it is generally considered that low-level radioactive liquid wastes may be disposed of by dilution, provided the maximum permissible concentration (8) in water is not exceeded in the receiving stream, the concentration of certain radioisotopes in aquatic organisms may make this hazardous. Foster (7) states that "if radiophosphorus were allowed to reach the maximum level permitted for drinking water, organisms living in the water would suffer radiation damage and the fish would be unsafe for human food." This is due to the high affinity for and concentration of radiophosphorus by aquatic organisms. Perhaps some other radioisotopes may fall in this same category.

The fact that aquatic organisms concentrate certain radioisotopes to a high degree must be considered in many stream surveys and may be quite useful in others.

Following are a few examples of how various aquatic organism samples may be used in stream radioactivity surveys for different water uses.

Municipal Water Supplies

In monitoring a drinking water supply, the major consideration is, of course, the amount of radioactivity in the finished water. In most cases the amount in the raw water supply and the amount removed by water treatment processes is also of importance. The use of aquatic organism samples may be of considerable help in monitoring raw water supplies. Very low levels of radioactivity may be concentrated in plankton or algae samples and slight changes more readily detected than in water samples

alone. Continuously exposed samples of the stream biota may serve as a continuous monitoring system and may reflect accumulative releases of radioactive materials as well as concentrated slugs which intermittent collection of water samples may not detect.

In some water treatment plants it may be necessary to monitor the accumulation of plankton, algae, other biological growths, and silt on filter beds. These materials readily concentrate radioactivity, and while the danger to plant operators may be negligible, these materials may be released to the receiving stream through backwashing the filters. Fish, ducks, and other animals may use these concentrated materials for food or some other downstream water use may be affected.

Irrigation Waters

Very low levels of certain radioisotopes in irrigation waters may be concentrated by crops or livestock used for food. In the survey of a stream which may be used for irrigation, the analysis of aquatic organism samples may indicate the amount and kind of radioactive materials which may be of significance when using these waters for irrigation.

Industrial Waters

Very low radioactivity levels may be of significance in industrial water supplies, particularly in the manufacture of paper, chemicals, metals, etc., used in the photographic industry. The use of biological samples may help in detecting very small changes in radioactivity levels in water used for this purpose.

Waters Used for Recreation or Commercial Fisheries

In surveys of waters used for these purposes, aquatic organism samples are necessary. The effect on aquatic populations and the use of fish, shellfish, or other aquatic organisms for human food must be determined. In many situations this may require biological investigations more extensive than merely the collection of samples for radiological determination. These investigations may include ecological studies of aquatic food chains and direct effects on organisms within the food chain. Studies may be necessary of effects on the reproduction of fishes, their migrations, and their availability to and extent of use by the public.

While it appears that most radioactivity may be concentrated in bones and other waste parts of fish, some commercial species are canned whole. Other aquatic animals such as mollusks, crabs, crayfish, etc., are used for human food. Ducks, geese, and other waterfowl may concentrate and carry activity for many miles, and other wild and domestic animals may feed on aquatic vegetation.

Waste Disposal

The use of biological samples may help in studies of the dispersal of radioactive wastes in receiving waters. A study can determine the possible effects of radioactive wastes on downstream water uses more adequately if the sampling program includes the collection and analysis of aquatic organism samples.

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(3) Foster, M. F., and Rostenbach, R. E. "Distribution of Radioisotopes in the Columbia River." Jour. A.W.W.A., Vol. 46, 633-40 (1954).

(4) Krumholz, L. A., "Observations on the Fish Populations of a Lake Contaminated by Radioactive Wastes." Bull. Am. Museum of Nat. Hist., Vol. 110, Art. 4, 281-367 (1956).

(5) Cherubin L. J. "Potential Hazards Associated with the Release of Laboratory Liquid Waste to the Mohawk River." USAEC Pub. No. TID-7517, 406-409 (1956).

(6) Tsivoglou, E. C., Bartsch, A. F., Holiday, D. A., and Hushing, D. E. "Report of Contamination of Surface Waters by Uranium Recovery Plants." U. S. Public Health Service, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Mimeo. (1956).

(7) Foster, M. F., and Davis, J. J. "The Accumulation of Radioactive Substances in Aquatic Forms." Proc. United Nations Conf. on Peaceful Uses of Atomic Energy. Vol. 13, P/280, 364-67 (1956).

(8) National Bureau of Standards, Handbook No. 52, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water." U. S. Govt. Printing Office (1953).

The second part of this presentation included the demonstration of biological sampling equipment. A description of this equipment and methods of sample collection may be found in the following references:

Welch, Paul S., "Limnological Methods." The Blakiston Company, Philadelphia, Pennsylvania. 1948.

Lagler, K. F., "Freshwater Fishery Biology." Wm. C. Brown Co., Dubuque, Iowa, 1952.

Methods for the preparation of biological samples for radioactivity determination are described in detail in "Water Quality Studies on the Columbia," reference No. 1 in the preceding report.